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THE TEPHIGRAM [1]—ITS THEORY AND PRACTICAL USE IN WEATHER FORECASTING

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SYNOPSIS I. DESCRIPTION AND USE OF TEPHIGRAMS; II. GENERAL DISCUSSION; III. INDIVIDUAL DISCUSSION OF KITE ASCENTS; IV. CONCLUSIONS; V. TEPHIGRAMS

DESCRIPTION AND USE OF THE TEPHIGRAM

For a number of years it has been felt necessary to develop a method of plotting meteorological data on a thermodynamical basis. The common method of portraying the physical state of the atmosphere by plotting temperature or pressure against height is not very well suited for scientific thermodynamical discussions.

As early as 1884 Hertz gave a graphical method for the determination of the adiabatic changes of state of moist air. He used a double series of adiabatic lines, one series for saturated air, the other for unsaturated or dry air, to trace the behavior of air containing any given amount of water vapor. Neuhoff, a little later, elaborated on the method of Hertz and introduced an adiabatic chart which is now called the Neuhoff diagram. This diagram consists of a ground work of adiabatic lines for dry air and reversible adiabatics for saturated air, referred to temperature and the logarithm of pressure as coordinates.

Sir Napier Shaw has long studied the thermodynamical properties of the atmosphere. He was one of the first to see the advantages of the Hertz and Neuhoff diagrams. He carried his investigations still further. While on a Neuhoff diagram it may be ascertained whether the atmosphere on any specific occasion as defined by the observations from an airplane flight or registering balloon is in stable equilibrium or not, there is no means by which an estimate may be made as to the consequences which will result from the departure from the conditions of equilibrium. To make such an estimate possible it is necessary to have a diagram with coordinates by which energy can be represented. From these considerations Shaw finally devised a method of plotting upper-air data in the form of a curve, which he has called the tephigram. This curve is plotted on squared paper on which the ordinates represent entropy (ϕ) or the logarithm of potential temperature (θ) and the abscissæ absolute temperature (T). Total entropy of moist air includes the entropy of dry air and also that of the water vapor. On this diagram dry air alone is regarded as the working substance and any moisture carried along is regarded as a reservoir of latent energy which is realized when condensation takes place, all other effects of water vapor are neglected. Only this realized entropy is shown; loss of water and the latent heat of condensation are compensated for by increasing the realized entropy of the dry air.

With the above coordinate system, any area measured represents work, or $\int T d\phi$. By means of a planimeter this area can be measured and its actual numerical value in energy units computed. Since entropy, ϕ, is proportional to the logarithm of potential temperature, θ

$$\phi = C_p \log \theta + K,$$

Shaw found it more convenient to work directly with entropy. Entropy is found from the equation

$$\phi = C_p \log \frac{T}{T_0} - \frac{\mathrm{R}}{\mathrm{m}} \log \frac{p}{p_0} = C_p \log \frac{T}{100} - \frac{\gamma - 1}{\gamma} C_p \log \frac{p}{1{,}000},$$

the entropy being measured with reference to the point $T_0 = 100°$ C. *A.*, $p_0 = 1{,}000$ millibars.

From the last equation Shaw has computed tables for the entropy using the following constants:

$$C_p = 0.2417 \times 4.18 \times (10)^7 \text{ c. g. s. units}$$
$$\gamma = 1.40.$$

By using the temperature in C° and pressure in millibars as given by the recording instruments, the entropy can be conveniently and rapidly found.

Below is a brief description of a temperature-entropy diagram (fig. 1) with a short résumé of the equations from which the various lines shown on the diagram may be computed. Horizontal lines, being lines of constant entropy and constant potential temperature, are dry adiabatics. Vertical lines are isotherms. The lines of equal pressure slope downward to the right and can be computed from the equation of entropy,

$$\phi = C_p \log \frac{T}{T_0} - \frac{\mathrm{R}}{\mathrm{m}} \log \frac{p}{p_0},$$

where T_0 is equal to 100° C. and p_0 is 1,000 millibars. The saturated or irreversible adiabatics curve upward to the right, gradually becoming parallel to the dry adiabatics in the lower pressure regions. These lines are computed from the equation

$$C_p \log T - \frac{\mathrm{R}}{\mathrm{m}} \log p + 0.622 \frac{re}{pT} = K,$$

which is similar in form to Poisson's equation with an addition to take care of the water-vapor content. These lines are really the so-called pseudo adiabatic lines in contradistinction to the true or reversible adiabatics. That is, the water vapor is condensed and falls out as a mass of air is cooled, and the amount precipitated can be actually determined by means of the water-vapor content or so-called saturation lines. The dotted lines, nearly perpendicular to the isobars are lines showing the number of grams of water vapor which will saturate 1 kilogram of dry air. These lines are drawn from the equation

$$q = \epsilon \frac{e_m}{b - e_m(1 - \epsilon)} \quad (q = \text{specific humidity})$$

[1] Submitted in partial fulfillment of the requirement for the degree of master of science from the Massachusetts Institute of Technology, 1929. First published in Professional Notes of the Meteorological Course of the Massachusetts Institute of Technology. This explains why the numbers of the figures do not run consecutively.

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in which ϵ is the specific gravity of water vapor with reference to dry air and is taken as 0.622, e_m saturation water vapor pressure, b the barometric pressure. The amount of water which has been condensed and precipitated can be ascertained by noting the differences between the index of the saturation line through the point at which saturation was reached and that of the saturation line through the final position of the tracing point.

A tephigram as previously defined is the curve plotted on the temperature entropy diagram showing the actual observed conditions of the atmosphere. Once the coordinates are obtained, it is a simple procedure to plot in the curve. The interpretation of this curve is by no means difficult. If moisture did not exist in the atmosphere the plotting of upper air data and reasonably correct deductions therefrom would be quite simple. But moisture is as important as lapse rate in all considerations of stability. Therefore, it is necessary to indicate the water content of the air if the diagrams are to be of any practical value. This is done by plotting a curve of dew points in connection with the tephigram.

To illustrate the foregoing, a sample tephigram is shown on Figure 1. The changes of temperature and entropy from the surface to the highest point reached in the troposphere are shown by the curve AKCDFG, the tephigram. If the air at the point marked A were saturated, the energy which would be liberated as one kilogram of air rose pseudo-adiabatically from A to F is indicated by the whole area shaded on the diagram. The upper boundary of the area is an adiabatic line for saturated air and it will be seen since the line AF is everywhere to the left of the tephigram AKCDF, the rising air will be warmer throughout than its environment. It will, therefore, have buoyancy and be capable of doing work as it rises. When the area lies above the tephigram it is called positive area and represents energy available for producing convection and instability, which in turn gives rise to thunderstorms and other weather disturbances. An area below the tephigram, as AKB, is called negative area and represents stability, since spontaneous ascent of the air in this case is not possible. An explanation of this area will be given later on.

Spontaneous ascent of saturated air can occur only in regions where the saturation adiabatic through the starting point keeps on the warm side of—that is, above—the tephigram. This implies instability for saturated air. A deviation of the tephigram upward from the saturated adiabatic indicates stability for saturated air. Spontaneous ascent of dry air can occur only in regions where the graph of the sounding slopes downward from the horizontal, implying instability for dry air, that is, a super adiabatic lapse rate. Stability is indicated by a deviation of the tephigram upward from the horizontal. Temperature inversions are shown by deviation of the tephigram to the left of the vertical, and isothermal regions by no deviation from the vertical.

The method of plotting humidities is to plot the dew points as well as the air temperature on each pressure line. On the diagram (fig. 1) "A" shows the temperature 292° at 990 millibars pressure and "a" the dew

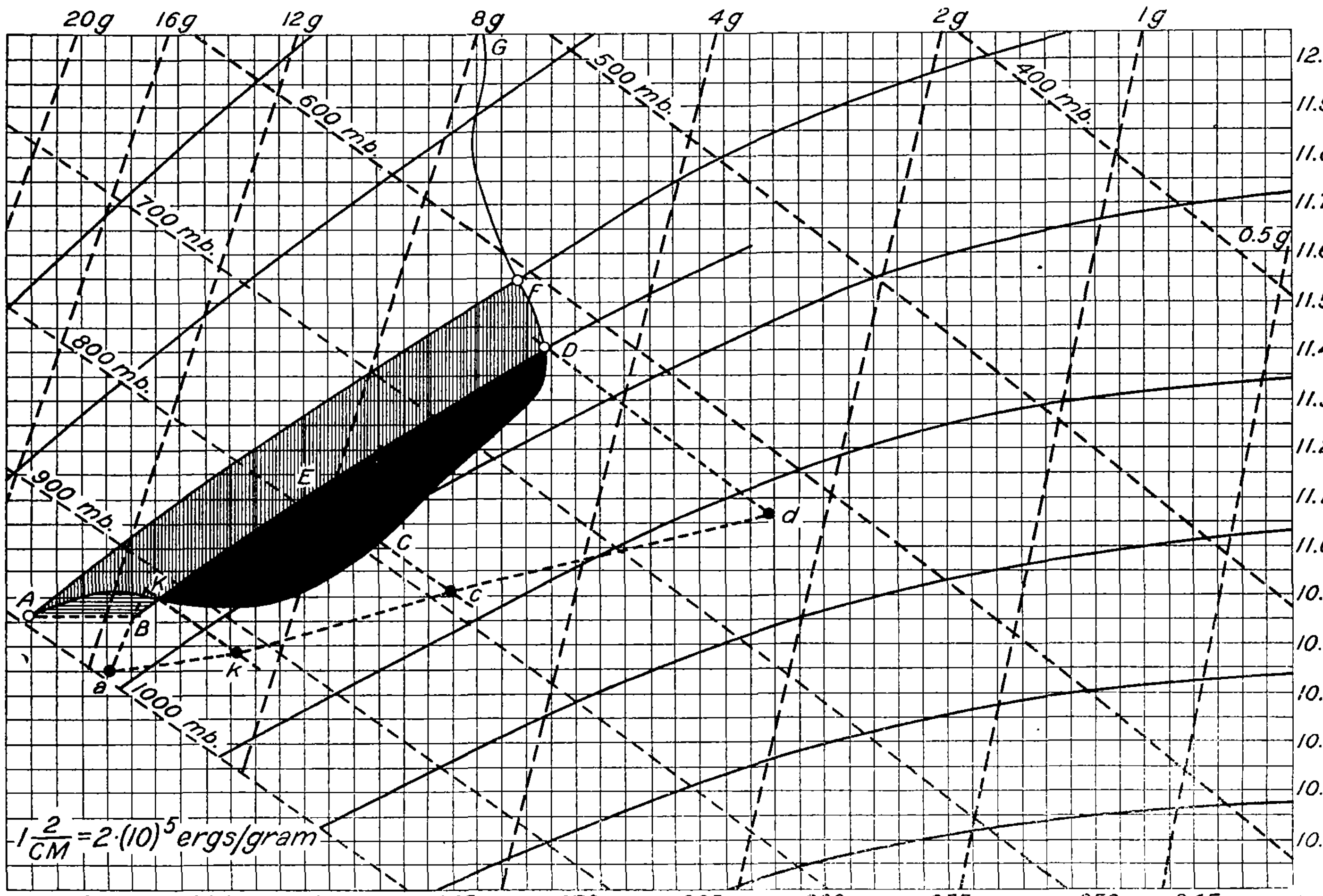

FIGURE 1.—Sample tephigram; for the sake of simplicity the temperature and entropy lines have been omitted

point 289° C. A. at the same pressure. After having compared several diagrams, the length of the line Aa gives an indication of the dryness of the air. This method shows the variations of humidity throughout an ascent, but it does not appear suitable for the study of the energy available in a mass of air rising from a particular layer. Such a curve of dew points is called a depegram, and on the figure it is represented by the dotted line "akcd."

Mr. J. S. Dines has put forth an alternative plan; that is, to calculate the weight of water vapor per kilogram of dry air present at the level, A. Through A draw a horizontal line to B. This point B marks the temperature at which this calculated weight of water vapor is the saturated content of the air. The water vapor content lines on the diagram make the plotting of the point B easy. Actually, the above process simply illustrates the path of a moving particle of air. It starts from some level where it is not saturated, rises along the dry adiabatic until it becomes saturated (at B), and from there continues along the wet adiabatic; that is, in the rain stage. (Sir Napier Shaw has pointed out that in the application of thermo-dynamics to practical meteorology the snow and hail stages may be omitted.) During the first stage ABK, the air will be colder than its surroundings and work will have to be done on the particle to raise it (negative area). During its course along KED it will be warmer than its surroundings, rise of its own accord, and will do work, liberate energy, as indicated by the double hatched area on Figure 1. This area then is the measure of the available energy. By this method of plotting, instability of the atmosphere may be studied. It makes it plain where large quantities of energy would be available if the air were saturated, whereas in conditions actually existing due to the fact that the air is not completely saturated, the available energy is greatly reduced, often becoming negative.

The area bounded by the tephigram and the adiabatic followed is a measure of the convective energy that can be made available through a displacement of the kilogram of air considered. In the accompanying graphs positive areas are shaded red, negative areas, blue.[2]

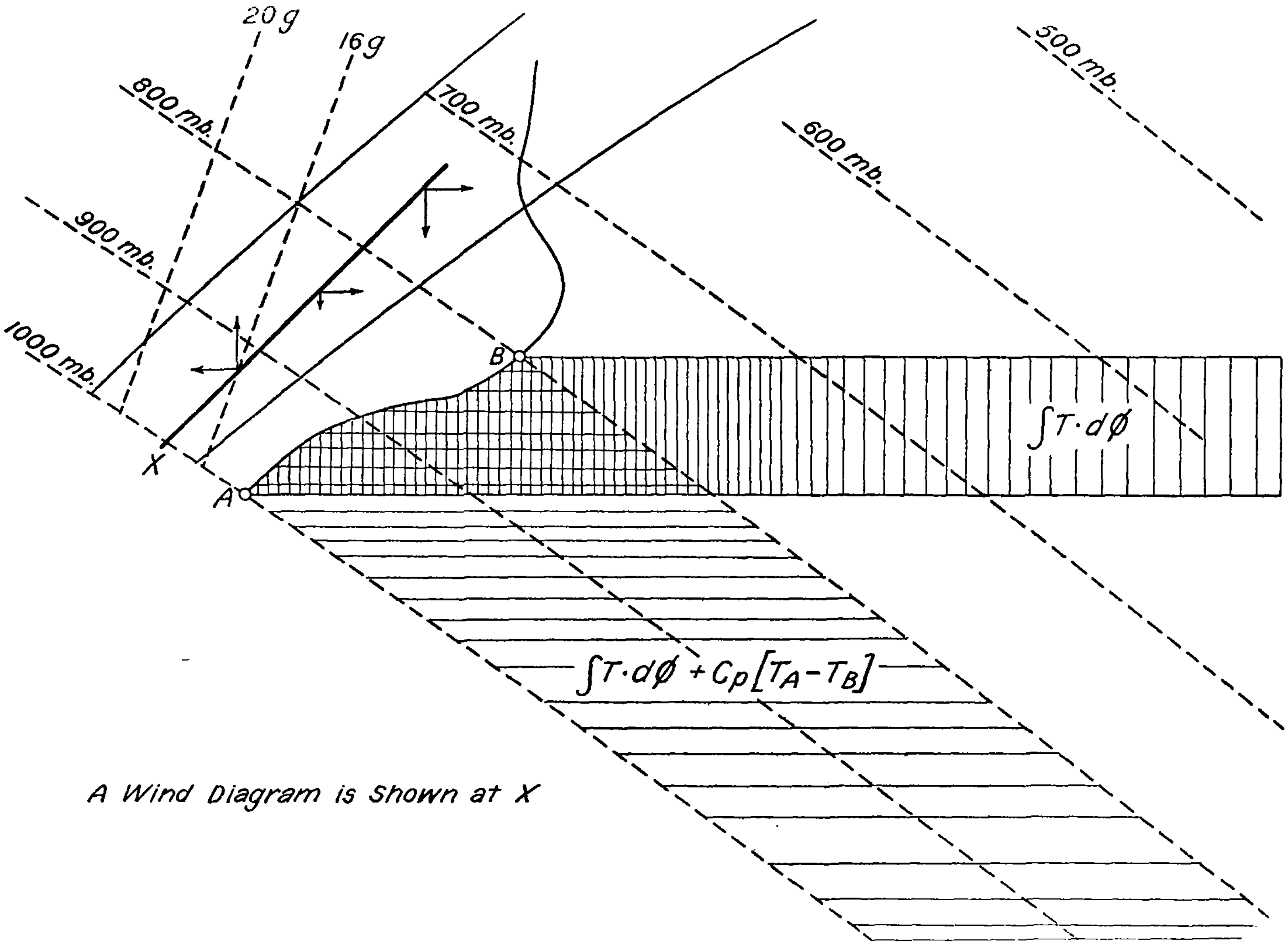

FIGURE 2.—Computation of height by means of the tephigram. The horizontal shaded area extended to absolute zero by the continuation of the 800 and 1,000 millibars isobars represents the change of geopotential from A to B. The area vertically hatched, extending from the $T\phi$ gram, A-B, to absolute zero, is a measure of $\int T.\, d\phi$

Height can also be computed by means of the ϕT-diagram as shown by Sir Napier Shaw in the following manner. The geopotential of a particle, from which the altitude is easily derived, is the energy required to lift it against gravity to its position. Therefore the problem is simply that of finding the value of $\int_0^z g.\, dz$

Let E be the geopotential at any height.

[2] In order to avoid the necessity of printing in two colors the positive areas in red are printed in solid black and the negative areas in blue are shaded.

$$dE = g \,.\, dz$$
$$dp = -g\rho dz$$
$$dp = -\rho dE$$
$$dE = \frac{-dp}{p} \cdot \frac{RT}{m} = \frac{-RT}{m} d(\log p)$$

From the definition of potential temperature (θ) it follows that

$$\log p_0 - \log p = \frac{mCp}{R} [\log \theta - \log T]$$

p_0 = constant standard pressure

$$-d(\log p) = \frac{mCp}{R} [d(\log \theta) - d(\log T)]$$

Thus,

$$dE = TC_p[d(\log \theta) - d(\log T)]$$
$$E = \int T.Cp\; d(\log \theta) - Cp \int dT$$

But,

$$\phi = Cp \;.\; \log \theta + K$$
$$d\phi = Cp \;.\; d(\log \theta)$$

Therefore

$$E = \int T d\phi + Cp(T_0 - T)$$

T_0 = temperature at level from which E is counted.

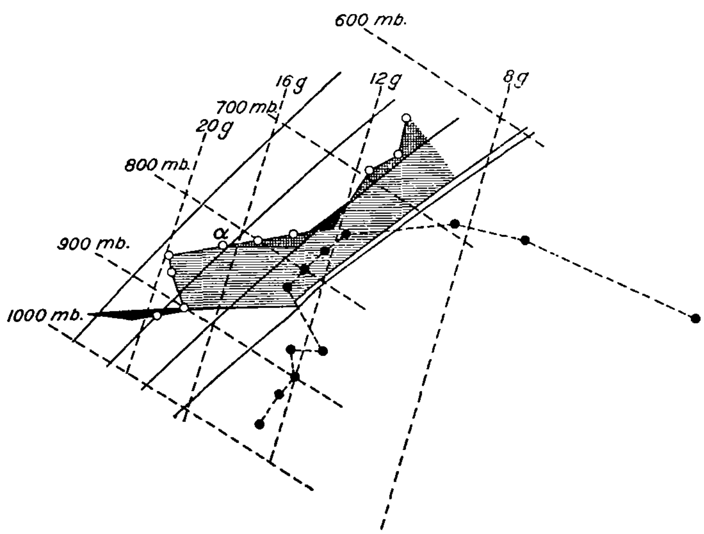

FIGURE 4.—Drexel, September 5, 1917, 2:51 p. m. On this diagram energy areas are given both with respect to a kilogram of air from the surface layer and with respect to a kilogram of air originating at α, as shown by difference in shading

$\int T d\phi$ = energy in c. g. s. units represented by the area bounded by the tephigram and line of 0° A and two horizontal lines ϕ_0 and ϕ_1. (This is the energy communicated from the outside.) $Cp(T_0 - T_1)$ is the energy in c. g. s. units which is taken from the material of the rising mass on account of change in temperature. This is energy contributed from the material itself. E, the total amount of energy involved in the process, which can also be measured on the diagram by the area bounded by the tephigram and the pressure lines through these points down to 0° A, is calculated as follows.

Consider in Figure 2 two points on the tephigram A and B. To calculate the height between these two points we first get the value of $\int T d\phi$ by measuring the area on the diagram bounded by the curve AB and vertical line through 0° A and the horizontal lines ϕ_a and ϕ_b by planimeter or counting the squares. This area equals 383 square centimeters. The diagram is so constructed that 1 square centimeter $= 2 \times 10^5$ ergs. $383 \times 2 \times 10^5 = 766 \times 10^5$ ergs = 766 geodynamic meters. To obtain the other component $C_p(T_0 - T_1)$ from A to B, we need only know the temperature difference between these two points (10.6° C.)

$$1.01 \times 10^7 \times 10.6 = 10.706 \times 10^7 \text{ ergs.} \quad Cp = 1.01 \times 10^7$$
$$= 1{,}070.6 \text{ g. d. m.}$$

The total height = 1,070.6 + 766 = 1,836.6 geodynamic meters. To obtain height in meters Bjerknes' tables are used and for latitude 45° N. the result is 1,875 meters.

To make the diagram complete there is still to be added a means by which the velocity and direction of the wind at the various altitudes may be represented. This is done by means of what Shaw calls the "clothes line" diagram. Since we usually think of an increase of altitude as a reduction of pressure, and since the isobars run nearly at an angle of 45° with the diagram, a line at approximately right angles to the isobars will well illustrate a vertical. On this line at the heights desired, the wind vectors are placed. Using a scale of 1 mm. = 1 m. p. s. and the vectors laid with north toward the top and east toward the right on the diagram, a convenient graphical representation of the wind at any altitude may be shown. Such a "clothes line" diagram is shown on Figure 2 at X.

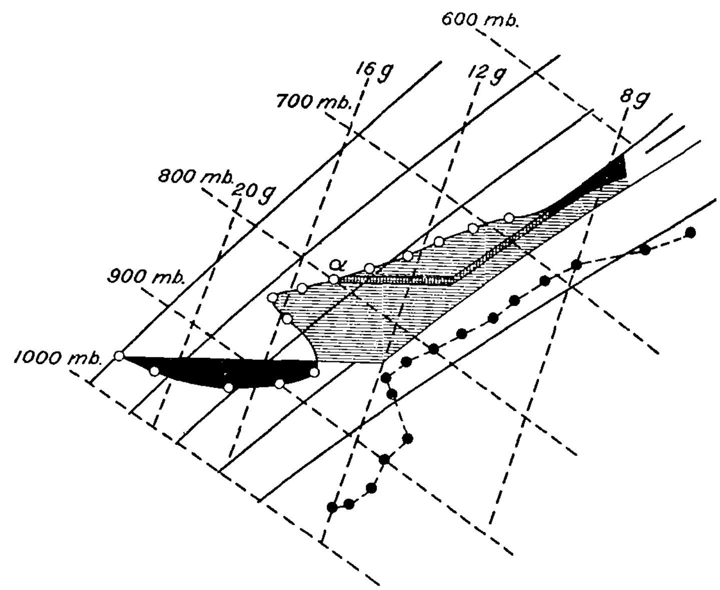

FIGURE 5.—Drexel, September 5, 1917, 4:50 p. m. On this diagram energy areas are given with respect to a kilogram of air from the surface layer and with respect to a kilogram of air originating at α, as indicated by difference in shading

The most important use, however, of the temperature-entropy diagram is the representation of the upper air by means of the tephigram. While the other additions are important and useful and should be represented for future use, they would take too much time to compute for immediate use. The tephigram on the other hand, can quickly and easily be made. To show that it is a valuable aid to forecasting is the purpose of the following discussion of certain weather conditions in the United States.

II. GENERAL DISCUSSION

The principal practical use to which tephigrams may be put is that of local forecasting. From a study of numerous tephigrams indicating available energy it is found that they may be divided into two broad types; (a) frontal type, that is those which give an indication of the approach and passage of a boundary between different air masses, and (b) convective type, those which show a pure convection type of disturbance within a homogeneous air mass.

These broad divisions were made by analyses of the synoptic charts in conjunction with the tephigrams for the same periods. As an example of the frontal type the series of graphs from Drexel (Nebr.) beginning with the 5th of September, 1917, 7:16 a. m. is used. (Figs. 4, 5, 6.) The morning ascent (not reproduced) shows a very stable atmosphere to great height; the depegram shows low relative humidity. By 3 p. m., as graph 4 shows, a region of conditioned instability had developed at a height of 840 millibars, with a remarkable increase in humidity. The small positive area at the surface is due to surface convection, but that at the height of 750 millibars can be due only to the bringing in of a new air mass. It may be remarked here that when a tephigram becomes more or less horizontal with a marked angular shift (which indicates a steeper lapse rate, that is, an abrupt change to instability) at some higher level above 900 millibars, it seems to be an indication of some frontal disturbance. At least this conclusion seems justified from the present study of tephigrams. By 4:50 p. m. the positive area had increased, although at a greater altitude. The positive area due to surface heating had

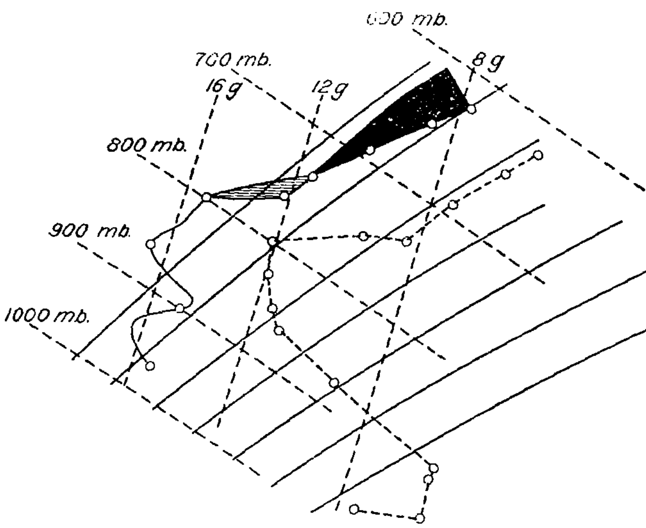

FIGURE 6.—Tephigram, Drexel, Nebr., September 5, 1917, 6:50 p. m.

also increased. At 6:50 p. m. the surface convection had ceased and the atmosphere up to 800 millibars was quite stable. But now the positive area aloft has increased to a remarkable extent and some strong disturbance could be expected. At 10:45 p. m. a thunderstorm passed over the station.

As a good example of the convection type, the graph of an airplane ascent made at Anacostia, D. C., on the morning of August 2, 1928, at 10 o'clock is used. (Fig. 9.) Here the outstanding feature is the enormous positive area extending from the surface upwards. The tephigram shows no leveling off, but is more or less a curve with a constant slope. That is, there is no abrupt change in the lapse rate. Also there is the marked superadiabatic lapse rate at the surface. The depegram follows the general form of the tephigram which is also another characteristic of this type of disturbance. A thunderstorm occurred on this day at about 4 p. m.

III. INDIVIDUAL DISCUSSION OF KITE ASCENTS

Under this heading each series of ascents will be discussed separately. First, will be taken those tephigrams which show frontal disturbance and last, those which show the convective type. Between the two is given an example which appears to be a combination of the two types.

The synoptic maps for the 7th and 8th of May, 1918 do not indicate to any great extent what the weather conditions will be in the neighborhood of Drexel. From the tephigram for the 8th of May at 8:57 a. m. (fig. 12) with the sudden change from the stable lapse rate to the very steep one above 900 millibars accompanied with increase of relative humidity, one could see the first

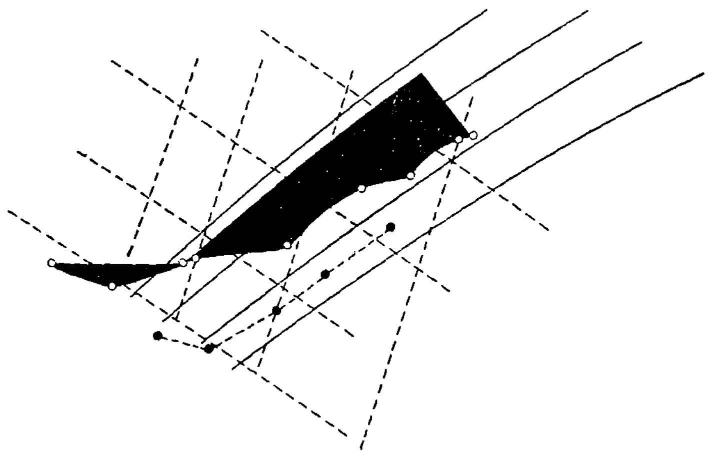

FIGURE 9.—Aerograph flight 111-28 Anacostia, D. C., August 2, 1918, 9:56 a. m.

approach of the over running cold air. Even at the ground a kilogram of air would possess a certain amount of positive energy, as is shown by the full shaded area, while by considering a kilogram mass of air at the 890 millibars level, the positive area is tripled. From the tephigram alone one could expect thunderstorms and other disturbances following the passage of a cold front. The thunder was heard at 11 a. m. indicating the approach of a squall line. Thunderstorms occurred in the afternoon of May 8, and also the morning of the 9th.

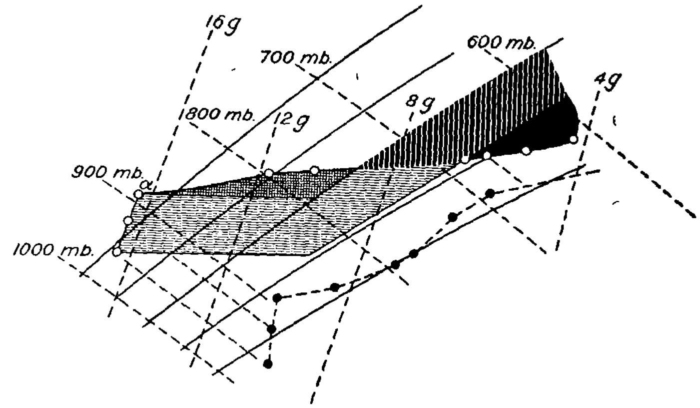

FIGURE 12.—Drexel, May 8, 1918, 8:57 a. m. On this diagram energy areas are given with respect to a kilogram of air from the surface layer and with respect to a kilogram of air originating at α

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The graphs for Drexel on June 11 (figs. 13 and 14) are good examples of the appearance of tephigrams when cold air is brought in at higher altitudes. The graph for 6:21 a. m. shows great stability from the ground to 900 millibars. From 900 to 800 millibars the lapse rate has become steeper than that for saturated air, but the water vapor content has not increased to any great extent, and the relative humidity is still quite low. At 800 millibars, however, the air becomes very unstable, the lapse rate changes abruptly to the superadiabatic, and the relative humidity increases rapidly. This implies a different air mass in this upper region, which is borne out by an inspection of the synoptic maps for this period. A cold front is approaching and this is an indication of overrunning cold air.

The graph for noon of that day shows a small positive area above 600 millibars. This area itself would not indicate any great disturbance, but here we must rely on our previous knowledge of weather sequence following

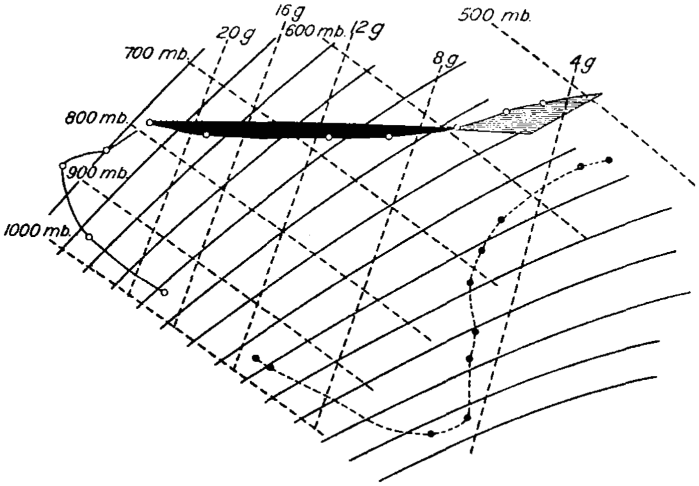

FIGURE 13.—Tephigram, Drexel, Nebr., June 11, 1918, 6:21 a. m.

such weather conditions. Thunderstorms could be safely predicted as well as cold front rains. At 6 : 23 p. m. the squall line was observed approaching.

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The series beginning with April 1, 1918, 8 : 03 a. m. at Drexel (figs. 15 and 16), depicts the bringing in of cold air between the 1st and 2d of April. Graph 15 shows great

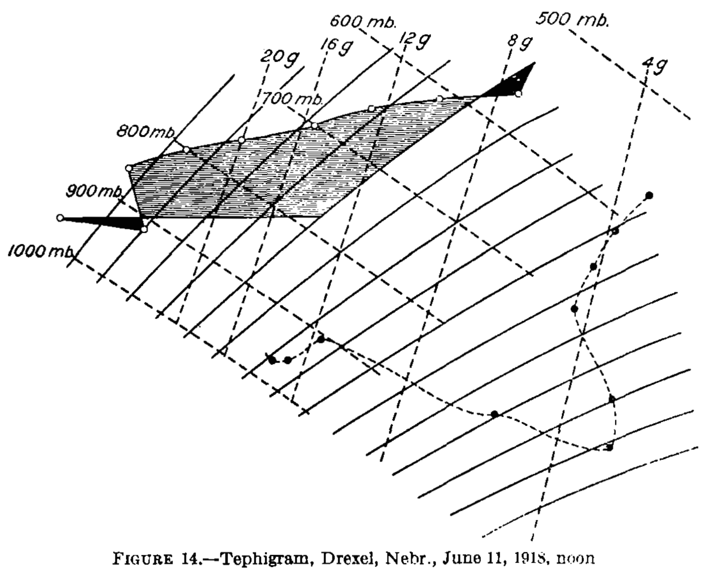

FIGURE 14.—Tephigram, Drexel, Nebr., June 11, 1918, noon

stability in a homogeneous air mass. On April 2 at noon (fig. 16), although there is a positive area at the ground, the real significant point is the superadiabatic lapse rate at 820 millibars. The curve of dew points follows in general the tephigram until 820 millibars, where the relative humidity begins to increase with altitude. From such a tephigram one could expect the weather which would occur with the approach and passage of a cold front. Rain, turning to sleet, and thunder followed shortly after this graph was taken.

* * * * *

At Ellendale on May 30, 1918, the tephigram for 9 p. m. (fig. 26) showed stability from the surface to 700 millibars. At that point there is an abrupt increase in humidity and the lapse rate becomes superadiabatic. This, as has been shown, would indicate a new air mass

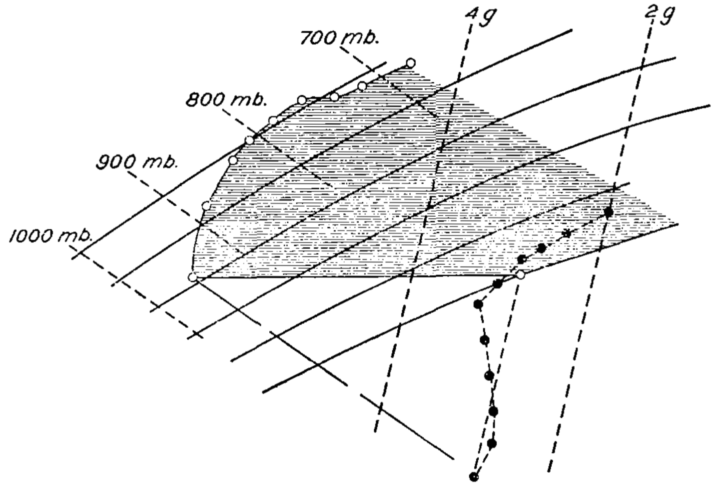

FIGURE 15.—Tephigram, Drexel, Nebr., April 1, 1918, 8:03 a. m.

being brought in aloft. Although no thunderstorms occurred in the vicinity of Ellendale, lightning was observed in a distance.

The next morning, however, there is a remarkable change in the structure of the atmosphere. As the synoptic maps show, a southerly current has been brought in and as the tephigram shows (fig. 27), this

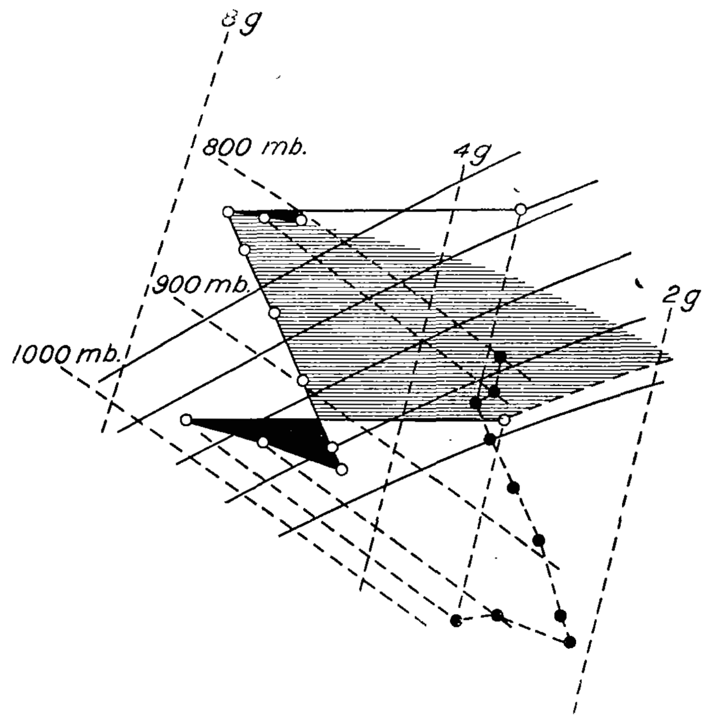

FIGURE 16.—Tephigram, Drexel, Nebr., April 2, 1918, 11:59 a. m.

mass extends from the surface to high levels. The great instability shown on this graph, May 31, 1918, is caused by convection, and the thunderstorm which could easily be forecast, occurred at 5 : 30 p. m.

This series is an example of convection coupled with the instability of a new air mass brought in giving rise to thunderstorms.

* * * * *

The tephigrams heretofore considered have been the frontal type, with one example of a transition type in which convection has played an important part. The remainder of the discussion will concern a few cases which show the instability caused solely by convection. The first one here discussed, that of Drexel (fig. 34), on August 16 at 8 : 25 a. m., is an excellent example. The tephigram shows a moderate amount of positive area at the surface extending up to 900 millibars. From 900 to 750 the air is stable and an area of negative energy exists. Above this there is positive energy. It is reasonable to assume on the basis of experience that a thunderstorm will occur during the afternoon. At 2 : 15 p. m. a tephigram shows that the negative area has been wiped out completely, so now we can expect a thunderstorm in the very near future. At 2 : 30 p. m. one was forming to the northwest. Since in forecasting at least a 6-hour forecast should be made, the tephigram of 2 : 15 p. m. (fig. 35) would not be of much use. However, in this case from Figure 34 there is hardly any doubt, as said above, but that a thunderstorm would occur in the afternoon.

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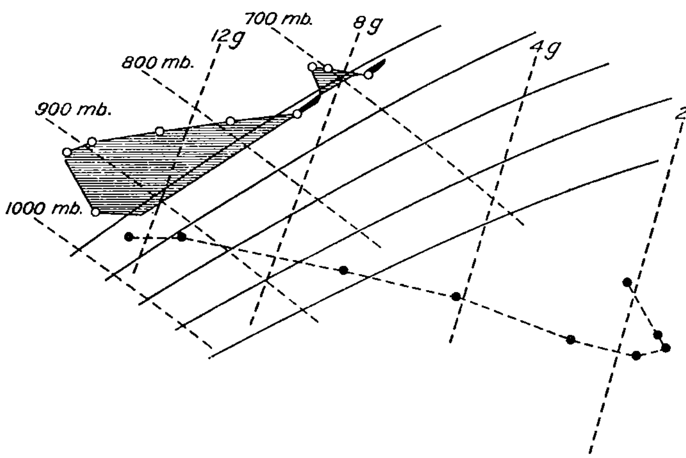

FIGURE 26.—Tephigram, Ellendale, N. Dak., May 30, 1918, 9 p. m.

At Ellendale on June 6, 1918, at 8:12 a. m., a tephigram (fig. 39) shows instability in the lower levels with a marked temperature inversion below 900 millibars. The positive area near the surface appears to be a little above normal for the time of day, but above this there is only negative area extending up to about 540 millibars showing a stable stratification at high levels. The weather remained clear all of that day and night. The following day shortly after noon a tephigram (fig. 40) has very much the same characteristics near the surface with an inversion just above 900 millibars. Above the inversion there is a small amount of positive area showing that conditions are more favorable for some form of weather disturbance. At 5 p. m. the same afternoon, there was thunder and lightning to the south of the station, and the next day there was a thunderstorm at the station itself.

* * * * *

On August 20, 1918, at 1:05 p. m. at Drexel, a tephigram shows a normal moderate amount of positive area in lower levels with instability due to surface heating. From 850 to 750 millibars the air became stable, giving a negative area for this region. Above is positive energy extending to the top of the curve. Conditions appear to be favorable for thunderstorms sometime later in the afternoon or night. A tephigram (fig. 46), plotted from data taken the next morning, shows positive area at the surface and at high levels, with negative area in between, and a marked inversion from 920 to 880 millibars. At 3:55 p. m. that afternoon a tephigram (fig. 47) shows that the inversion has been wiped out through increased surface convection and the negative area greatly reduced. From this we can assume that conditions are favorable for a thunderstorm in a few hours. About 6 p. m. one occurred 8 miles away.

IV. CONCLUSIONS

The conclusion which we have drawn from the present study of tephigrams is that they are valuable aids in making short-range forecasts. There is hardly any doubt but that in most cases a convection thunderstorm can be foretold at least six hours in advance from the graph of an upper air sounding made in the morning, and there is hardly any need to dwell on the importance of this for local forecasting. One can readily understand its value to an aviation landing field. In the summer time thunderstorms occur without any regularity, and the morning of a day on which a thunderstorm occurs looks much the same as one which remains fair. Further, it is believed that the approach of line squalls or frontal disturbances

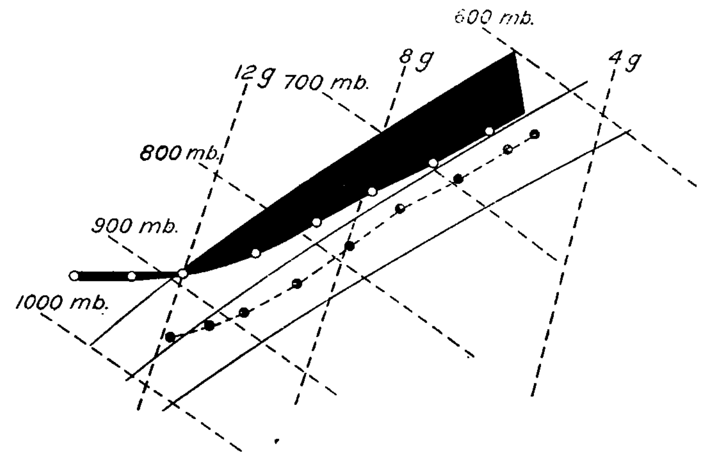

FIGURE 27.—Tephigram, Ellendale, N. Dak., May 31, 1918, 11:08 a. m.

can be foretold with a great deal of accuracy, especially when the tephigrams are used in conjunction with the daily synoptic maps. This latter information, to be sure, is of the greatest importance to aviation, and with careful analysis of successive tephigrams it is believed that positive information can be obtained.

It is believed that to anyone familiar with the use of tephigrams, they soon become indispensable for local forecasting, especially where an upper air sounding and local weather observations constitute the total amount of data available; that is, the tephigram fills the gap in information for an isolated observer, one who is out of communication with the world at large for an indefinite period of time.

Certain rules seem to be brought out by the present study of tephigrams. They will be briefly stated below.

(1) It is easily seen that a small error in the relative humidity will make a large error in the amount of energy available (positive energy). This would indicate that the hygrograph used must be reliable and carefully calibrated.

(2) The other rules apply to the tephigram itself. For instance, it is not safe to extrapolate a tephigram. If the sounding has not reached a sufficient altitude, it is of little or no value. An altitude of 15,000 feet or above 700 millibars of pressure at least ought to be obtained, and this would seem to make the use of airplane ascents

imperative. The present study convinced the authors that kite ascents are of little value since a sufficient altitude is very seldom reached.

(3) The best time to make a flight or sounding is 8:30 a. m. or later (local mean time). This conclusion was reached after a comparison of the tephigrams. Before 8:30 a. m. the tephigrams do not have any individual characteristics; all are a great deal alike. In other words,

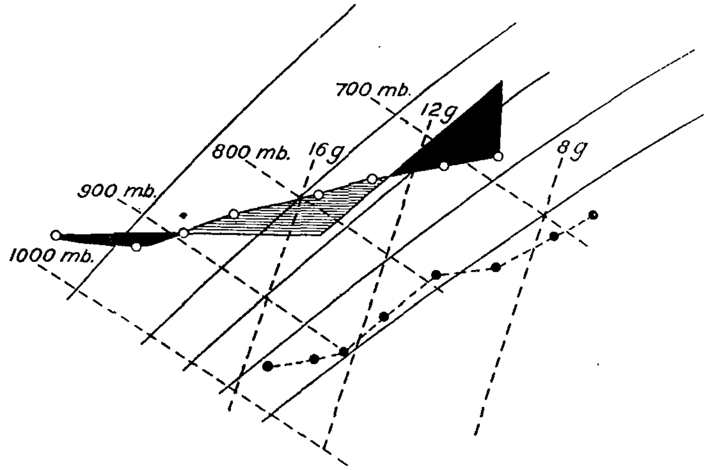

FIGURE 34.—Tephigram, Drexel, Nebr., August 16, 1918, 8:52 a. m.

it is better to wait until a little later, when the action of local heating may be observed. This suggestion is merely tentative, however, and the observer at each station would have to learn from experience the best time to make the first and succeeding flights.

(4) As to the size and importance of the energy areas, this may be said: The actual numerical measure of an area on one tephigram can not be compared with the area on another tephigram, as to the relative intensity of disturbances produced unless the tephigrams are in succession. A comparison of consecutive areas gives a better result.

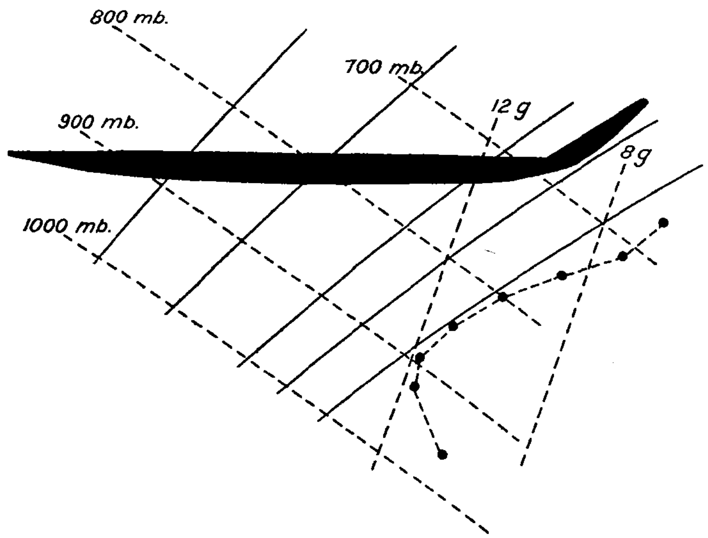

FIGURE 35.—Tephigram, Drexel, Nebr., August 16, 1918, 2:15 p. m.

For example, when a negative area is being reduced on succeeding graphs it is of as great importance as when a positive area increases. Also the relative size of positive and negative areas on the same $t-\phi$ diagram is very important. A small positive area at the surface, below a large negative area, indicates stability. The reason for this is that the small amount of instability in the surface layers is due only to the surface heating and extends only through the first few hundred meters. The large negative area is an indication of the great stability of the higher layers of the atmosphere, and for weather disturbances to be produced the effect of local heating (convection) would have to destroy the stability of the upper layers; that is, wipe out the negative area. On the other hand, when a large positive area is near the surface and a small negative area separates it from a still higher positive area, the atmosphere is in a potentially unstable condition. In this case the convection started in the surface layers would soon produce a strong uninterrupted vertical stream of air. The greater the moisture and heat content of this current the greater will be the ensuing disturbance and the quicker the negative area on the diagram will disappear or change to a positive area. As to the question whether a narrow belt of positive energy extending to a greater height is of more importance than a wide belt of positive energy in the lower layers of at least as great numerical magnitude, nothing really definite has been proved. From the few comparisons which can be made from the present study, it would appear that the narrow belt indicates more a frontal disturbance, with a greater release of energy, while the lower wider belt of energy is of the convective type. In the discussion under the heading of "frontal type of tephigrams," the important characteristics of this type have been brought out. It is important to notice that on a frontal type of tephigram an invasion of a new air mass is indicated more by the change of the temperature lapse rate and humidity

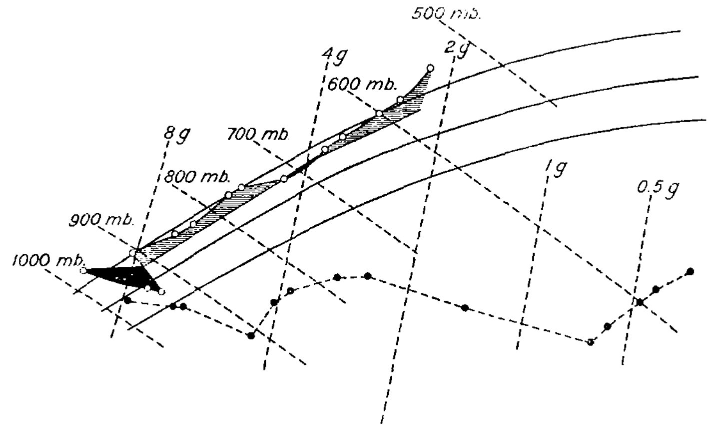

FIGURE 39.—Tephigram, Ellendale, N. Dak., June 6, 1918, 8:12 a. m.

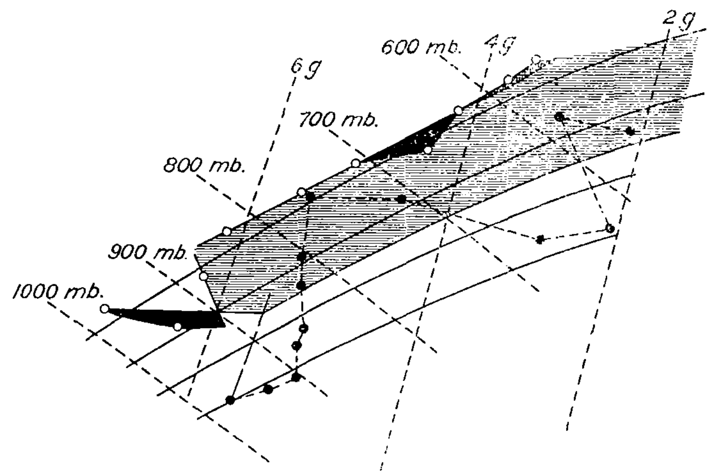

FIGURE 40.—Tephigram, Ellendale, N. Dak., June 7, 1918, 12:13 p. m.

than by the appearance of positive energy areas. The graph strikingly portrays this by the change of the slope of the tephigram and depegram. However, if with the approach of a new air mass no positive energy appears, it seems to indicate that there will be no violent thunderstorms in the neighborhood of the station itself.

(5) In some cases we have indicated positive and negative areas with reference to a unit mass of air taken at some other altitude than at the surface. In some cases, where there has been no positive area shown with reference to the surface, there is a positive area with reference to a higher point. Sometimes the positive area increases, sometimes decreases. In general, it may be stated that in the case of the approach and passage of a different air mass (frontal disturbance) the positive area increases, or the negative decreases, on succeeding graphs, while at the same time on any one graph the positive area seems to increase as the reference level of energy available is shifted upward. While it is true also of the convection type that succeeding graphs will show a gradual increase of positive area, the positive area on a single graph appears to decrease as the starting or reference point is moved upward. Theoretically, the total energy present in a certain layer could be found by adding the energy at each level, that is a more or less graphical integration of the positive and negative areas.

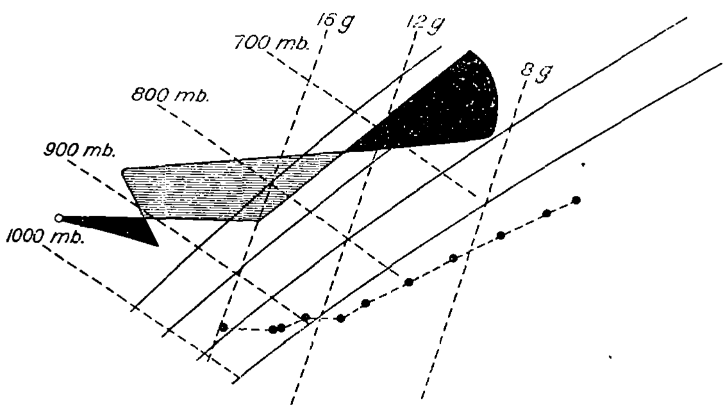

FIGURE 46.—Tephigram, Drexel, Nebr., August 21, 1918, 8:49 a. m.

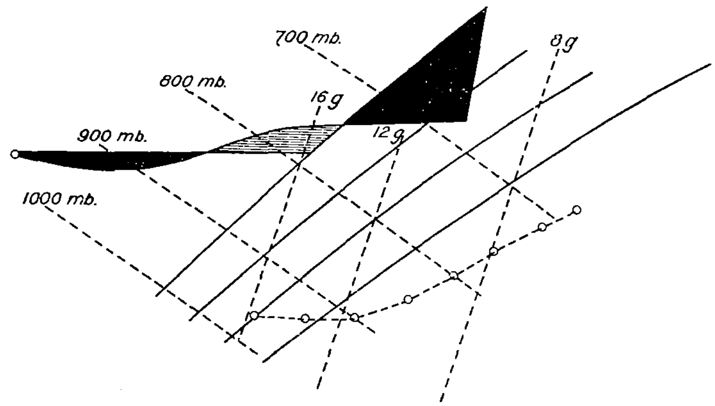

FIGURE 47.—Tephigram, Drexel, Nebr., August 21, 1918, 3:55 p. m.

Much can be written and said on the subject of tephigrams. Actually little practical use has been made, at least in America, up to the present time. This paper falls far short of any real comprehensive study of the subject, but it is hoped that enough has been shown to indicate the practical value of tephigrams as an aid in forecasting.

551.48 (794)

SOURCES OF LOCAL WATER SUPPLY [1]

By A. SONDERLEGGER, consulting engineer, Los Angeles, Calif.

It is a matter of general comment among the population of southern California that of late years we have passed through a period of drought. We have had one dry year after another; in fact, since the great floods of 1914 and 1916, we have had only three years of abnormal rainfall, while the other 10 years have been dry. Yet, we keep on pumping cheerfully from seemingly unlimited underground sources and nobody appears to worry very much except the superintendent of the water works.

The assertion is sometimes advanced that there are mysterious underground streams, or rivers, which convey water from the Mojave Desert to the Coastal Plain, or from as far distant sources as the Colorado River. There are no indications, or facts, in support of any such contentions. The mountain ranges which separate us from the desert are plutonic in origin. They are many miles in thickness and there are no passages or cavities to permit either a flow or a percolation of water across them.

Rainfall.—The water supply of any region in southern California depends entirely upon the rain falling on its contributory watershed and a study of rainfall phenomena will, therefore, disclose the basic factors affecting our water supply.

Rainstorms.—The major storms which drift from the Pacific Ocean over southern and central California are the result of areas of low barometer, usually moving from northwest to southeast. These storms are the most frequent bearers of our rainfall. They are general over the whole region and, as a rule, of fairly uniform relative intensity. The records of seasonal precipitation of any station thus are an index for a broad area.

Effect of altitude on rainfall.—The moisture-laden storm winds strike the coast from the southeast, south, and southwest. On encountering the mountains along the coast and in the interior they are forced to rise to higher altitudes, where they are cooled and precipitate a larger portion of their moisture. Thus with increasing altitude we find correspondingly larger precipitation up to about 6,000 feet, above which there is a slight decrease. This process of absorption of moisture is so effective that after passing the succession of ranges which parallel the coast there is little moisture left beyond the High Sierras, and the country to the east thereof is naturally barren. This phenomenon is illustrated on Plate 1, which represents a profile transverse to the major axis of the State, from the coast of San Luis Obispo easterly across the Santa Lucia Range to the San Joaquin Valley and thence over the High Sierras to Owens Valley and Death Valley. This is also illustrated on the same plate by a profile from the coast at Long Beach across the southern Coastal Plain and San Gabriel Valley, passing Mount Wilson of the Sierra Madre Range and on down to Palmdale in the Mojave Desert.

Rainfall cycles.—The rainfall of southern California is characterized by extreme irregularity not only from day to day or month to month of a rainy season, but also

[1] A collection of papers presented before the school of citizenship and public administration, University of Southern California, June 17-21, 1929.